IDENTIFICATION OF THE INSTREAM FLOW REQUIREMENTS FOR ANADROMOUS FISH IN THE STREAMS WITHIN THE CENTRAL VALLEY OF CALIFORNIA

Annual Progress Report
Fiscal Year 2000

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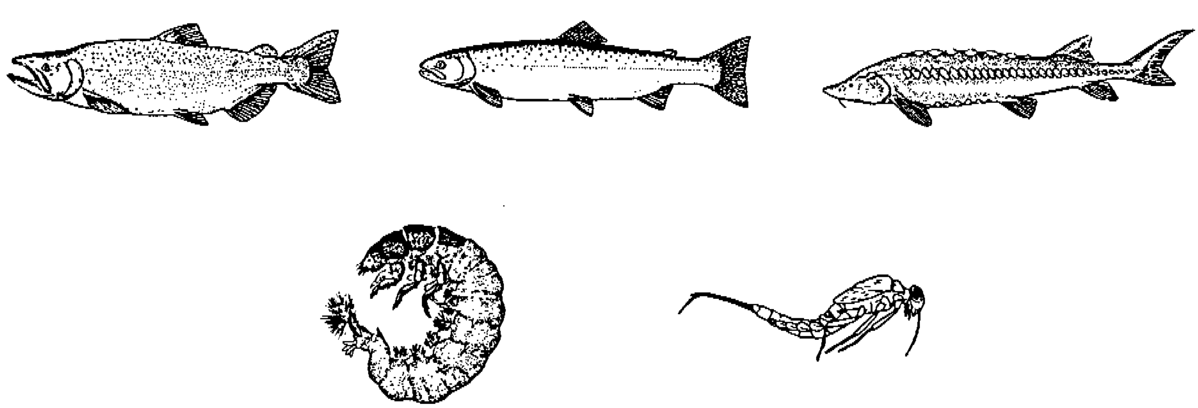

PREFACE

The following is the sixth annual progress report prepared as part of the Central Valley Project Improvement Act Instream Flow Investigations, a 7-year effort which began in February, 1995. Title 34, Section 3406(b)(1)(B) of the Central Valley Project Improvement Act, P.L. 102-575, requires the Secretary of the Interior to determine instream flow needs for anadromous fish for all Central Valley Project controlled streams and rivers, based on recommendations of the U.S. Fish and Wildlife Service (FWS) after consultation with the California Department of Fish and Game (CDFG). The purpose of this investigation is to provide reliable scientific information to the U.S. Fish and Wildlife Service Central Valley Project Improvement Act Program to be used to develop such recommendations for Central Valley rivers.

The fieldwork described herein was conducted by Ed Ballard, Mark Gard, Erin Sauls, Rick Williams, John Kelly, Jerry Big Eagle, Larry Thompson, Rich DeHaven, Justin Ly and Elizabeth Irwin.

To those who are interested, comments and information regarding this program and the habitat resources of Central Valley rivers are welcomed. Written comments or information can be submitted to:

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INTRODUCTION

In response to substantial declines in anadromous fish populations, the Central Valley Project Improvement Act requires the doubling of the natural production of anadromous fish stocks, including the four races of chinook salmon (fall, late fall, winter, and spring), steelhead trout, and white and green sturgeon. In December 1994, the USFWS, Ecological Services, Instream Flow Assessments Branch prepared a study proposal to use the Service's Instream Flow Incremental Methodology (IFIM) to identify the instream flow requirements for anadromous fish in selected streams within the Central Valley of California. Subsequently, as discussed in our first annual report, the Sacramento, lower American and Merced Rivers were selected for study. In February 1998, the USFWS, Fish and Wildlife Office, Energy, Power and Instream Flow Assessments Branch prepared an updared study proposal. The updated study proposal added other streams, principally Butte Creek, to the above three selected for study. The studies on these rivers have been and will continue to be closely coordinated with study efforts being conducted by CDFG.

The Sacramento River study is a seven-year effort to be concluded in September, 2001. Specific goals of the study are to determine the relationship between streamflow and physical habitat availability for all life stages of chinook salmon (fall-, late fall-, winter-runs) and to identify flows at which redd dewatering and juvenile stranding conditions occur. The instream flow requirements for white and green sturgeon may also be studied; however, the inclusion of these species depends upon the availability of resources and sufficient data to enable identification of the habitats used by them. The study components include: 1) compilation and review of existing information; 2) consultation with other agencies and biologists; 3) field reconnaissance; 4) development of habitat suitability criteria (HSC); 5) study site selection and transect placement; 6) hydraulic and structural data collection; 7) construction and calibration of reliable hydraulic simulation models; 8) construction of habitat models to predict physical habitat availability over a range of river discharges; and 9) preparation of draft and final reports. The FY2000 Scope of Work (SOW) identified study tasks to be undertaken. These included: study site selection, and hydraulic and structural data collection (study components 5 and 6); construction of hydraulic models (study component 7); and continuing the development of HSC (study component 4).

The lower American River study was a one-year effort which culminated in a March 27, 1996 report detailing the methods and results of this effort. This report was submitted to CDFG for enclosure in their final report on the lower American River. Subsequently, questions arose as to which of the chinook salmon spawning HSC criteria used in the March 27, 1996 report would be transferable to the Lower American River. As a result, additional field work was conducted in FY97, culminating in a supplemental report submitted to CDFG on February 11, 1997. As a result of substantial changes in the Lower American River study sites from the January 1997 storms, a second round of habitat data collection and modeling was begun in April 1998. Data collection for this effort was completed in February 1999 and a final report will be prepared by September 2000.

The Merced River study was a 1.5 year effort which culminated in a March 19, 1997 report detailing the methods and results of this effort. This report was submitted to CDFG for enclosure in their final report on the Merced River.

The Butte Creek study is a 2 year effort which started with collection of spring-run chinook salmon spawning habitat suitability criteria during September 1999. In May 2000, fieldwork was begun to determine the relationship between habitat availability (spawning) and streamflow for spring-run chinook salmon. This fieldwork included study site selection, transect placement and hydraulic and structural data collection. Collection of spring-run chinook salmon spawning habitat suitability criteria will be completed in September 2000.

The following sections summarize project activities between October, 1999 and September, 2000.

SACRAMENTO RIVER

Study Site Selection

In FY2000, we investigated potential study sites between Keswick Reservoir and Battle Creek where stranding flows for juvenile chinook salmon will be identified. The following section describes the methods employed and the results of FY2000 study site selection efforts for this species.

Juvenile chinook salmon stranding areas

We surveyed both banks of the Sacramento River from Keswick Dam to Battle Creek to identify locations where juvenile chinook salmon could become trapped in inundated areas isolated from the main river channel when Sacramento River flows drop. Our surveys were conducted at relatively low flows (less than 8,000 cfs). The criteria that we used to identify stranding areas were: 1) the area would not drain to the main river channel; 2) the area would strand at river flows ranging from 3,250 to 15,000 cfs; and 3) the area was not the mouth of a tributary. We found 107 locations which would become isolated from the main channel at flows ranging from 3,250 to 15,000 cfs. Twenty-seven of these sites were identified in October 1998. The remaining sites were identified in December 1999 and January and April 2000. The location of these sites are identified in Appendix A.

Study site setup

Juvenile chinook salmon stranding areas

Three main approaches were used to determine the stranding flows[1] for the 107 stranding sites: 1) for those stranding sites located in one of our juvenile habitat modeling sites, the 2-dimensional hydraulic model of the juvenile habitat site will be used to determine the stranding flow for the stranding site; 2) for those stranding sites where the flow during our identification of the stranding site was at or slightly above or below the stranding flow for that site, we determined the stranding flow based on the flow on that date; and 3) for the remaining sites, we developed a stage-discharge relationship for the main river channel at the stranding site to determine the stranding flow. The first two categories of sites did not require any site setup or data collection, while the third category of site required the installation of a vertical benchmark (generally a lagbolt in a tree).

Hydraulic and Structural Data Collection

Juvenile chinook salmon stranding areas

Areas will be determined for all of the 107 stranding sites. For smaller sites, we have determined the area by measuring the length and two to six widths of the stranding site, using an electronic distance meter; the area is calculated by multiplying the length times the average width. The areas of larger sites have been measured on aerial photos using a planimeter. We have determined the area of 57 of the 107 stranding sites (Appendix A).

Stage-discharge relationships will be developed for 53 of the 107 stranding sites. Data required for developing a stage discharge relationship are: 1) water surface elevations (WSELs, stages) collected at three flows; and 2) the stage of zero flow. We also measured the bed elevation of the stranding point (the lowest point at the connection between the stranding area and the main river channel); the stage at the stranding flow was calculated by adding 0.1 feet to the bed elevation of the stranding point. After the stage discharge relationship is developed, it is used to determine what the flow is at the stranding flow stage. We have measured WSELs at three flows for 26 sites, at two flows for 18 sites and at one flow for 7 sites; we are waiting to set up the remaining two sites until we can observe them at lower flows to determine if they will drain to the main river channel. For most of the sites, the stage of zero flow was determined by making an ADCP run across the main channel at the stranding point. For a few sites on side channels where the

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[1] We have defined the stranding flow as the flow where the connection between the stranding area and main river channel has a maximum depth of 0.1 feet. We selected 0.1 feet because the minimum depth at which we have found juvenile salmon during our HSI data collection has been 0.2 feet. When flows drop to or below the stranding flow, juvenile salmon will be isolated from the main river channel.

entire channel could be waded, the stage of zero flow was determined by measuring depths across the side channel with a wading rod. In both cases, the stage of zero flow was calculated as the difference between the WSEL on that date and the largest depth. We have determined the stage of zero flow for all but four of the 53 stage-discharge stranding sites. We have measured the stranding bed elevations for all but nine of the 53 stage-discharge stranding sites. We have completed the stage-discharge relationship and determined the stranding flow for 13 of the 53 stage-discharge stranding sites (Appendix A). We have also determined the stranding flow for 17 of the remaining 54 stranding sites (Appendix A).

Chinook salmon spawning habitat

Hydraulic and structural data collection on the six fall-run chinook salmon spawning sites (Five Fingers Riffle, Blackberry Riffle, Osborne Riffle, Upper Bend Riffle, Jellys Ferry and Mudball Riffle) between Battle Creek and Deer Creek, which began in August 1999, continued through FY2000. As discussed in the FY1999 progress report, these sites will be modeled using two-dimensional hydraulic and habitat modeling. The 2-D model uses as inputs the bed topography and substrate of a site, and the water surface elevation at the bottom of the site, to predict the amount of habitat present in the site. A PHABSIM transect at the bottom of the site (outflow transect) is used to provide the water surface elevations used by the 2-D model, while the water surface elevations predicted by a PHABSIM transect at the top of the site (inflow transect) are used to calibrate the 2-D model. The data collected at the inflow and outflow transects include: 1) water surface elevations (WSELs), measured to the nearest .01 foot at a minimum of three significantly different stream discharges using standard surveying techniques (differential leveling); 2) wetted streambed elevations determined by subtracting the measured depth from the surveyed WSEL at a measured flow; 3) dry ground elevations to points above bankfull discharge surveyed to the nearest 0.1 foot; 4) mean water column velocities measured at a mid-to-high-range flow at the points where bed elevations were taken; and 5) substrate and cover classification at these same locations and also where dry ground elevations were surveyed. Data collected between the transects include: 1) bed elevation; 2) northing and easting (horizontal location); 3) cover; and
4) substrate. These parameters are collected at enough points to characterize the bed topography, substrate and cover of the site.

Water surface elevations have been collected at a mid-flow (approximately 10,000 cfs) and at around 30,000 cfs for the inflow and outflow transects at all six sites, while low flow (approximately 5,000 cfs) water surface elevation have been collected at all sites except Five Fingers Riffle and high flow (approximately 15,000 cfs) water surface elevations have been collected at all sites except Blackberry and Five Fingers Riffles. Velocity sets have been collected for the transects at all sites except Five Fingers Riffle. Depth and velocity measurements in portions of the transects with depths greater than three feet were made with the ADCP, while depths and velocity measurements in shallower areas were made by wading with a wading rod equipped with a Marsh-McBirney[R] model 2000 or a Price AA velocity meter. Vertical benchmarks have now been tied together at all of the sites. Dry bed elevations have been collected on the transects at Mudball Riffle, Jellys Ferry and Upper Bend Riffle sites. We have used two techniques to collect the data between the top and bottom transects: 1) for areas that are dry or shallow (less than three feet), bed elevation and horizontal location of individual points are obtained with a total station, while the cover and substrate are visually assessed at each point; and 2) in portions of the site with depths greater than three feet, the ADCP is used in concert with the total station to obtain bed elevation and horizontal location. Specifically, the ADCP is run across the channel at 50 to 150-foot intervals, with the initial and final horizontal location of each run measured by the total station. The water surface elevation of each ADCP run is measured with the level before starting the run. The water surface elevation of each run is then used together with the depths from the ADCP to determine the bed elevation of each point along the run. Velocities at each point measured by the ADCP will be used to validate the 2-D model. To validate the velocities predicted by the 2-D model for shallow areas within a site, depth, velocities, substrate and cover measurements were collected along the right and left banks within each site by wading with a wading rod equipped with a Marsh-McBirney^{R} model 2000 or a Price AA velocity meter. The horizontal locations and bed elevations were determined by taking a total station shot on a prism held at each point where depth and velocity were measured. A minimum of 25 representative points were measured along the length of each side of the river per site.

We have completed collection of both the dry/shallow bed elevation/substrate/cover data and the deep bed elevation data for all six sites. Shallow validation velocity data have been collected at Mudball, Osborne and Blackberry Riffle sites.

Chinook salmon rearing habitat

Hydraulic and structural data collection, which began in March 1998, was completed in March 2000.

Underwater video equipment and an electronic distance meter were used to determine the substrate and cover along the deeper portions of the transects, with the shallow and dry portions determined visually. The underwater video equipment consists of two cameras mounted on a 75 pound bomb at angles of 45 and 90 degrees. The 75 pound bomb is raised and lowered from our boat using a winch. Two monitors on the boat provide the views from the cameras. A grid on the 90 degree camera monitor calibrated at one foot above the bottom is used to measure the substrate and cover. Collection of dry/shallow and deep substrate and cover data along the transects of Salt Creek and Upper and Lower Lake Redding sites in FY2000 completed data collection for the upstream and downstream transects of the juvenile rearing sites.

Buoys placed prior to the collection of the deep bed data, at the initial and final location of each run, were used during the collection of the deep substrate and cover data. The underwater video and electronic distance meter were then used to determine the substrate and cover along each run, so that substrate and cover values could be assigned to each point of the run.

Collection of the dry and shallow bed elevation/horizontal location/substrate/cover data was completed in FY2000, with the collection of this data at the Salt Creek and Upper and Lower Lake Redding sites. Deep bed elevation/horizontal location/substrate/cover data was completed in FY2000, with the collection of this data in of parts of sites 112 and 15/17. Collection of validation velocity data was completed in FY2000 with the collection of this data for the Salt Creek and Upper and Lower Lake Redding sites.

Hydraulic Model Construction and Calibration

All of the data for the rearing sites between Keswick Dam and Battle Creek have been compiled and checked. PHABSIM data decks have been created and hydraulic calibration is in progress for the upstream and downstream transect for all of the rearing sites between Keswick Dam and Battle Creek. Input files for the 2-D modeling program have been prepared and hydraulic calibration is in progress for all of the rearing sites between Keswick Dam and Battle Creek.

Habitat Suitability Criteria (HSC) Development

Spawning

Methods

We attempted to locate fall and winter-run chinook salmon redds in shallow and deep water. We searched for shallow redds on foot and by boat. For both fall and winter-run chinook salmon, all of the active redds (those not covered with periphyton growth) within a given mesohabitat unit were measured. Data for shallow redds were collected from an area adjacent to the redd which was judged to have a similar depth and velocity as was present at the redd location prior to redd construction. This location was generally about two to four feet upstream of the pit of the redd; however it was sometimes necessary to make measurements at a 45 degree angle upstream, to the side, or behind the pit. The data were almost always collected within six feet of the pit of the redd. Depth was recorded to the nearest 0.1 ft and average water column velocity was recorded to the nearest 0.01 ft/s. Substrate was visually assessed for the dominant particle size range (i.e., range of 1-2") at three locations: 1) in front of the pit; 2) on the sides of the pit; and 3) in the tailspill. Substrate embeddedness data were not collected because the substrate adjacent to all of the redds sampled was predominantly unembedded. The substrate coding system used is shown in Table 1.

Location of redds in deep water was accomplished by boat using underwater video. Base aerial photos provided by CDFG showing the areas where winter-run chinook salmon redds have been observed in past years were used in locating the primary mesohabitat units where surveys were conducted. When searching for redds in deep water using underwater video, a series of parallel runs with the boat upstream within a mesohabitat unit was performed. After locating a redd in deep water, substrate size was measured using underwater video directly over the redds. Depth

Table 1
Substrate Descriptors and Codes

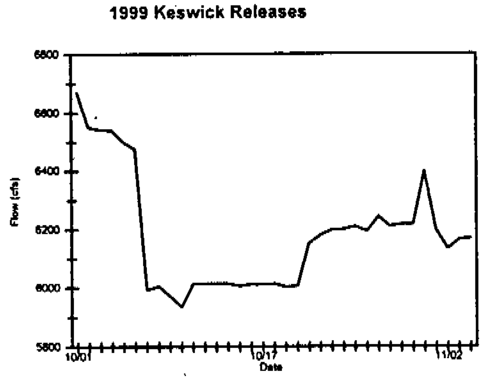
Code	Type	Particle Size (inches)
0.1	Sand/Silt	< 0.1
1	Small Gravel	0.1 - 1
1.2	Medium Gravel	1 - 2
1.3	Medium/Large Gravel	1 - 3
2.3	Large Gravel	2 - 3
2.4	Gravel/Cobble	2 - 4
3.4	Small Cobble	3 - 4
3.5	Small Cobble	3 - 5
4.6	Medium Cobble	4 - 6
6.8	Large Cobble	6 - 8
8	Large Cobble	8 - 12
9	Boulder/Bedrock	> 12

and water velocity was measured over the redds using the ADCP. The location of all redds (both in shallow and deep water) was recorded with a Global Positioning System (GPS) unit, so that we could ensure that redds were not measured twice. All data were entered into spreadsheets for eventual analysis and development of Suitability Indices (HSC).

Surveys for shallow and deep fall-run chinook salmon redds were conducted October 25-28 and November 1-4, 1999 to collect depth, velocity and substrate data. This effort completed our collection of fall-run spawning HSC data. Sacramento River flows (releases from Keswick Reservoir) averaged 6,107 cfs ± 4% from October 7 through November 4 (Figure 1). Since few fall-run salmon had started constructing redds prior to October 7, these steady flow conditions ensured that the measured depths and velocities were likely the same as those present at the time of redd construction.

Fall-run chinook salmon HSI criteria for depth and velocity were developed by calculating frequency distributions from the data collected in FY96, 97, 98 and 2000 and input into the

Figure 1



PHABSIM suitability index curve development program (CURVE). The HSI curves were then computed using exponential smoothing. The curves generated were exported into a spreadsheet and modified by truncating at the lower end, so that the next depth or velocity value below the lowest observed value had a SI value of zero; and eliminating points not needed to capture the basic shape of the curves.

Substrate criteria were developed by: 1) determining the number of redds with each substrate code (Table 1); 2) calculating the proportion of redds with each substrate code (number of redds with each substrate code divided by total number of redds); and 3) calculating the HSI value for each substrate code by dividing the proportion of redds in that substrate code by the proportion of redds with the most frequent substrate code.

The initial HSC showed suitability rapidly decreasing for depths greater than 1.75 feet. This effect was likely due to the low availability of deeper water in the Sacramento River with suitable velocities and substrates rather than a selection by the salmon of only shallow depths for spawning. The following method was used to correct the depth criteria for the low availability of deeper water with suitable velocities and substrates[2]. Based on the distribution of velocity and substrate redd data, we concluded that suitable velocities were between 0.93 and 2.66 ft/s, while suitable substrates were 1-3 to 3-5 inches in diameter (i.e., substrate codes 1.3, 2.3, 2.4, 3.4 and 3.5). A series of HSC sets were constructed where: 1) each set held velocity and substrate HSI values at 1.0 for the velocity and substrate range noted above with all other velocities and substrates assigned a value of 0.0; and 2) each set assigned a different one-foot depth increment an HSI value of 1.0 for depths between 1 and 14 feet deep, with the other one-foot increments and depths less than 1 foot and greater than 14 feet given a value of 0.0 (e.g., 1-2' depth HSI value equal 1.0, <1' and >2' depths HSI value equals 0.0 for set #1, etc.). Thus, thirteen sets of HSC were constructed differing only in the suitabilities assigned for optimum depth ranges. Each HSC set was run through the *RHABSIM* program using the output of the calibrated

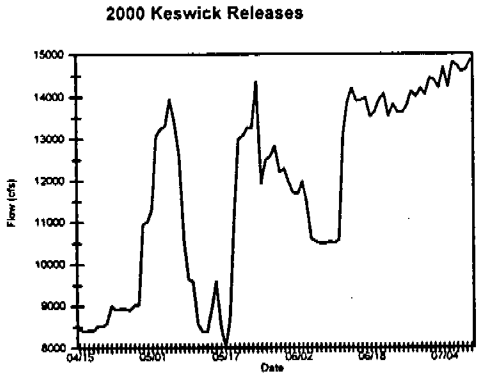
[2] See Gard 1998 for more information about this method.

hydraulic decks for the seven spawning habitat modeling sites at which HSC data was collected, with the resulting habitat output combined in a spreadsheet to determine the available river area with suitable velocities and substrates for the one-foot depth increments from 1 to 14 feet. The redd data from these seven sites were used to determine the number of redds in each of the above depth increments to assess use. Relative availability and use were then computed by dividing the availability and use for each depth increment by the largest availability or use, thus scaling both measures to have a maximum value of 1.0. Linear regressions of relative availability and use versus the midpoint of the depth increments (i.e., 1.5' for 1-2' depth increment) were used to remove noise from the data and produce linearized values of relative availability and use at the midpoints of the depth increments. The results of the regressions showed that availability dropped with increasing depth, but not quite as quickly as use. For the range of depths where the regression equations predicted positive relative use and availability, linearized use was divided by linearized availability, and the resulting ratios were scaled so that the maximum ratio was 1.0. A third linear regression of the scaled ratios versus the midpoint of the depth increments was used to determine the depth at which the scaled ratios reached zero. The result of this regression was that the scaled ratio reached zero at 48 feet; thus, the depth criteria were modified to have a linear decrease in suitability from 1.0 for the highest depth in the original criteria which had a suitability of 1.0, to a suitability of 0.0 at 48 feet.

Depth, velocity and substrate data were collected on winter-run chinook salmon redds on June 20-23, June 26-29, and July 10, 2000. Sacramento River flows (releases from Keswick Reservoir) varied considerably, from 8,000 to 14,865 cfs (Figure 2), from the initiation of winter-run spawning in mid-April through the end of sampling. Unfortunately, this adds a measure of uncertainty to HSI criteria to be developed from this data, since we can not be certain that the depths and velocities measured were similar to those during redd construction. Only 24% of the redds had fish holding on them (an indication of recent redd construction). Given the low population numbers of winter-run, it will likely be necessary to use data from this year despite the uncertainty in the data. To date, we have collected HSI data on 111 winter-run redds. It appears increasingly unlikely that we will be able to collect enough winter-run spawning data to develop HSC criteria. However, we have collected data on enough winter-run redds (minimum of 55 observations) to determine if fall-run spawning criteria can be transferred to winter-run salmon. The effort to collect spawning HSC data for the winter-run will continue for the 2001 spawning season, river conditions permitting.

Due to high turbidity and widely fluctuating flows (3,990 to 49,331 cfs) from mid-January through mid-April, it was impossible to collect any late fall-run HSC data. This chinook race spawns during the peak of the winter/early spring storm season (January through mid-April) when river flows are often very high and erratic. As a result, it appears increasingly unlikely that late fall-run spawning criteria can be developed in this study. The effort to collect spawning HSC data for the late fall-run will continue for the 2001 spawning season, river conditions permitting.

Figure 2



<u>Results</u>

Data were collected on a total of 63 fall-run chinook salmon redds. Sampling in FY2000 focused on equalizing effort (measured in days of sampling) between shallow (less than 3 feet) and deep areas, and on sampling within our spawning habitat modeling sites. Twenty-two mesohabitat units were sampled (three Bar Complex (BC) riffles, three BC Runs, two BC Glides, one BC Pool, four Flat Water (FW) Runs, two FW Riffles, five FW Glides, one FW Pool, and one Boulder Run). We spent an equal number of days sampling in shallow and deep areas for our overall fall-run chinook salmon spawning HSI data collection (in FY96, 97, 98 and 2000). Overall, we collected HSI data on a total of 437 fall-run chinook salmon redds. The HSI data had depths ranging from 0.5 to 13.8 feet, velocities ranging from 0.32 to 5.79 ft/s, and substrate sizes ranging from 1-2 inches to 4-6 inches. The final Sacramento River fall-run chinook salmon spawning HSI criteria are shown in Figures 3 to 5 and Appendix B.

Figure 3
Fall-run Chinook Salmon HSI Curve for Depth

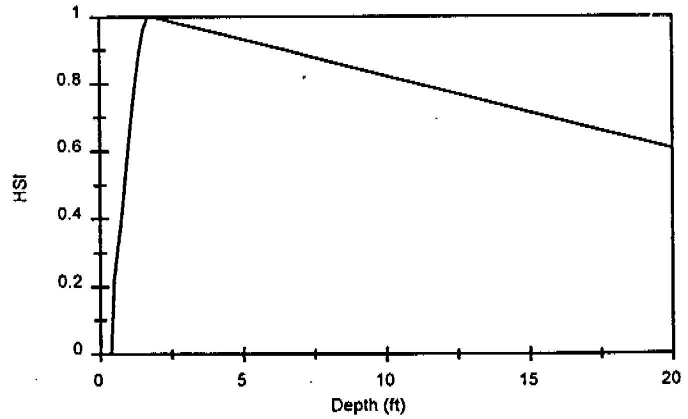


Figure 4
Fall-run Chinook Salmon HSI Curve for Velocity

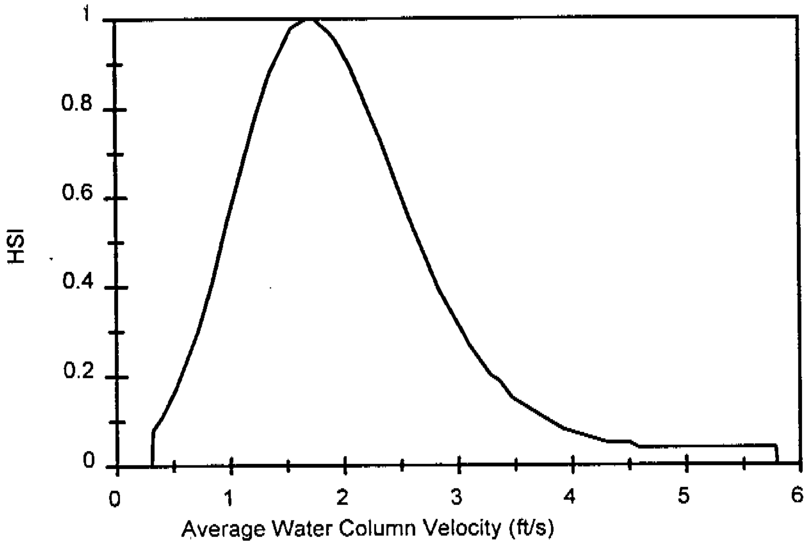
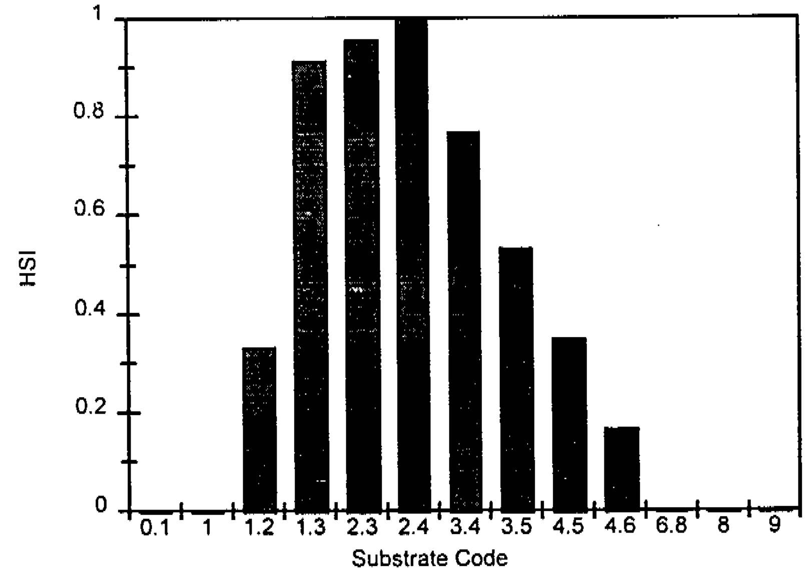


Figure 5
Fall-run Chinook Salmon HSI Curve for Substrate



Data were collected on a total of 69 winter-run chinook salmon redds (47 shallow and 22 deep redds). Twenty-five mesohabitat units were sampled (three Side Channel (SC) Riffles, one SC Run, four BC Runs, one BC Pool, one BC Glide, five BC Riffles, four FW Glides, two FW Riffles, two FW Runs, one FW Pool and one Boulder Run). The above mesohabitat units are areas where winter-run redds have been observed between Keswick Dam and Battle Creek in past aerial redd surveys. However, winter-run redds were only found in ten mesohabitat units (one FW Pool, two FW Riffles, three FW Glides, two FW Runs, and two SC Riffles, Table 2). As mentioned above, no data were collected for the late fall-run.

Table 2
1999 Winter-run Redd Locations

Location	Number of Redds
Mesohabitat Unit 140 (River Mile 299.9)	4
Upper Lake Redding	3
Bridge Riffle	6
Mesohabitat Unit 137 (River Mile 298.3)	1
Posse Grounds (Mesohabitat Units 135 and 136)	36
Turtle Bay Side Channels (Mesohabitat Unit 128)	6
Mesohabitat Unit 122 (River Mile 296.2)	4
Tobiasson Riffle	4
Mesohabitat Unit 84 (River Mile 289.8)	5

Rearing

HSC data were collected for chinook salmon fry and juveniles (YOY) on September 13-16, 1999 January 18-20, 2000, April 11-14, 2000 and July 18-21, 2000. Keswick releases were approximately 8,000 cfs during the September 1999 surveys, approximately 4,000 cfs during the January 2000 survey, approximately 8,500 cfs during the April 2000 survey and approximately 15,000 cfs during the July 2000 survey. As in previous years, data were collected in areas adjacent to the bank. However, greater emphasis was placed on scuba surveys of deeper water mesohabitat areas to try to equalize overall sampling effort between shallow and deep areas.

When conducting snorkeling surveys adjacent to the bank, one person would snorkel along the bank and place a weighted, numbered tag at each location where YOY chinook salmon were observed. The snorkeler would record the tag number, the cover code[3] and the number of individuals observed in each 10-20 mm size class on a PVC wrist cuff. Cover availability in the area sampled (percentage of the area with different cover types) and the length of bank sampled (measured with the electronic distance meter) would also be recorded. Another individual would retrieve the tags, measure the depth and mean water column velocity at the tag location, and record the data for each tag number. Depth was recorded to the nearest 0.1 ft and average water column velocity was recorded to the nearest 0.01 ft/s. An adjacent mean water column velocity was also measured within two feet[4] on either side of the tag where the velocity was the highest. This measurement was taken to eventually provide the option of using an alternative habitat model which considers adjacent velocities in assessing habitat quality. Adjacent velocity can be an important habitat variable as fish, particularly fry and juveniles, frequently reside in slow-water habitats adjacent to faster water where invertebrate drift is conveyed. Both the residence and adjacent velocity variables are important for fish to minimize the energy expenditure/food intake ratio and maintain growth. Data taken by the snorkeler and the measurer were correlated at each tag location and entered into a spreadsheet for eventual analysis and development of HSC.

Scuba surveys of deep water mesohabitat areas were conducted by first anchoring a rope longitudinally upstream through the area to be surveyed to facilitate upstream movement by the divers and increase diver safety. Two divers entered the water at the downstream end of the rope and proceeded along the rope upstream using climbing ascenders. One diver concentrated on surveying the water below and to the side, while the other diver concentrated on surveying the water above and to the side. When a juvenile salmon was observed, a weighted buoy was placed by the divers at the location of the observation. The cover code and the number of individuals observed in each 10-20 mm size class was then recorded on a PVC wrist cuff. Cover availability in the area sampled (percentage of the area with different cover types) and the length of river sampled (measured with the electronic distance meter) was also recorded. After the dive was completed, individuals in the boat retrieved each buoy and measured the water velocity and depth over that location with the ADCP. For each set of data collected using the ADCP for a juvenile fish observation, the average depth and velocity are considered the depth and velocity, while the maximum velocity is considered the adjacent velocity.

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[3] If there was no cover elements (as defined in Table 3) within one foot horizontally of the fish location, the cover code was 0 (no cover).

[4] Two feet was selected based on a mechanism of turbulent mixing transporting invertebrate drift from fast-water areas to adjacent slow-water areas where fry and juvenile salmon reside, taking into account that the size of turbulent eddies is approximately one-half of the mean river depth (Terry Waddle, USGS, personal communication), and assuming that the mean depth of the Sacramento River is around four feet (ie., four feet x ½ = two feet).

Table 3
Cover Coding System

Cover Category	Cover Code[5]
no cover	0
cobble	1
boulder	2
fine woody vegetation (< 1" diameter)	3
branches	4
log (> 1' diameter)	5
overhead cover (< 2' from water surface)	7
undercut bank	8
aquatic vegetation	9
rip-rap	10

All YOY chinook salmon observed have been classified by race according to a table provided by CDFG correlating race with life stage periodicity and total length. Data were also compiled on the length of each mesohabitat and cover type sampled to ensure that equal effort would eventually be spent in each mesohabitat and cover type and that each location was only sampled once at the same flow (to avoid problems with pseudo- replication). We will continue to sample one week every three months over the next nine months with continued effort to sample in mid-channel areas.

Starting with the April 2000 survey, we began to collect depth, velocity, adjacent velocity and cover data on locations which were not occupied by juvenile chinook salmon (unoccupied locations) so that we could apply a method presented in Rubin et al (1991) to explicitly take into account habitat availability in developing HSC criteria, without using preference ratios (use divided by availability). Traditionally criteria are created from observations of fish use by fitting a nonlinear function to the frequency of habitat use for each variable (depth, velocity, cover, adjacent velocity). One concern with this technique is what effect the availability of habitat has on the observed frequency of habitat use. For example, if cover is relatively rare in a

[5] In addition to these cover codes, we have been using the composite cover codes 3/7, 4/7, 5/7 and 9/7; for example, 4/7 would be branches plus overhead cover.

stream, fish will be found primarily not using cover simply because of the rarity of cover, rather than because they are selecting areas without cover. Rubin et al (1991) proposed a modification of the above technique where depth, velocity, cover and adjacent velocity data are collected both in locations where fish are present and in locations where fish are absent. Criteria are then developed by using a nonlinear regression procedure (suited to data with a Poisson distribution) with number of fish as the dependent variable and depth, velocity, cover and adjacent velocity as the independent variables, and all of the data (in both occupied and unoccupied locations) are used in the regression. An alternative approach is to use a logistic regression procedure, with the only difference being that the dependent variable is the presence or absence of fish. The HSC sampling methods presented above were modified as follows to allow for the collection of juvenile HSC data from both occupied locations (same method as above) and unoccupied locations.

Before going out into the field, a data book is prepared with one line for each unoccupied location where depth, velocity, cover and adjacent velocity will be measured. Each line has a distance from the bank, with a range of 0.5 to 10 feet by 0.5 foot increments, with the values produced by a random number generator.

One person snorkels the bank in the same method as described above dropping tags at locations of juvenile salmon. Two additional items are recorded by the snorkeler: the average and maximum distance from the water's edge that was sampled. A 300' tape is put out with one end tied at the location where the snorkeler finished and the other end loose with a small buoy attached. Three people go up the tape, one with a stadia rod and data book and the other two with a wading rod and velocity meter. At every 10' along the tape, the person with the stadia rod measures out the distance from the bank given in the data book. If there is a tag within 3' feet of the location, "tag within 3'" is recorded on that line in the data book and the people proceed to the next 10' mark on the tape, using the distance from the bank on the next line. If the location is beyond the sampling distance, based on the information recorded by the snorkeler, "beyond sampling distance" is recorded on that line and the recorder goes to the next line at that same location, repeating until reaching a line with a distance from the bank within the sampling distance. If there is no tag within 3' of that location, one of the people with the wading rod measures the depth, velocity, adjacent velocity and cover at that location. A fourth person follows behind and measures the depth, velocity and adjacent velocity at each tag location.

For areas that are sampled with SCUBA, the ADCP is turned on as we start to pull in the rope after the dive. The boat follows the course of the dive as the rope is pulled back into the boat. If there were any observations during the dive, the ADCP is stopped three feet before the location of the observation and started again three feet after the location of the observation. The ADCP is turned off at the location where the dive ended. A random number generator is used to select ADCP measurements of depth and velocity for unoccupied locations. The number of unoccupied cells selected for each site is the lesser of either 10% of the total distance (feet) sampled or 30% of the total number of ADCP points. For the SCUBA data, cover is assigned to all of the observations in proportion to which they were observed during the dive. The adjacent velocity for each unoccupied location is the largest of the three following values: the velocity at the location immediately prior to the unoccupied location, the velocity at the unoccupied location, and the velocity at the location immediately after the unoccupied location.

The data for both occupied and unoccupied locations described above will be combined with the previously-collected data on habitat use, and the resulting data set will be used to develop criteria as described above using either a nonlinear regression or logistic regression method.

Results

To date, we have taken 842 measurements (depth, velocity, adjacent velocity and cover) where YOY chinook salmon were observed. All but ten of these measurements were made near the river banks. There were 479 observations of fish less than 40 mm, 537 observations of 40-60 mm fish, 137 observations of 60-80 mm fish and 44 observations of fish greater than 80 mm[6]. According to the race classification table, these numbers account for 395 fall-run, 406 late fall-run, 5 spring-run, and 247 winter-run YOY chinook salmon observations. A total of 13.4 miles of near-bank habitat and 7.0 miles of mid-channel habitat have been sampled to date. Table 4 summarizes the number of feet of different mesohabitat types sampled to date and Table 5 summarizes the number of feet of different cover types sampled to date. We have sampled 51294 feet of cover group 0 and 19463 feet of cover group 1 in near-bank habitats, and 35768 feet of cover group 0 and 1247 feet of cover group 1 in mid-channel habitats[7]. We have 388 measurements for unoccupied locations (89 in shallow areas and 299 in deep areas).

Macroinvertebrate Criteria

We have embarked on developing a second set of juvenile chinook salmon HSI criteria - one based on food supply rather than physical habitat. Specifically, we will be developing HSI criteria for macroinvertebrate biomass and diversity. The criteria we develop will be run on the juvenile rearing site habitat models to predict the relationship between flow and habitat area for macroinvertebrate biomass and diversity. Macroinvertebrates are collected in a surber sampler with a 9-square-foot sampling area. The sampler is four feet high, so it can be used to sample

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[6] These numbers total much more than 842 because most of the observations included YOY of several size classes and only one measurement was made per group of closely associated individuals.

[7] As discussed in our FY-98 annual report, we grouped our cover codes into two groups; cover codes within each group are not statistically significantly different, while cover codes between the two groups are statistically significantly different. Cover group 0 consists of cover codes 0, 1, 2, 3, 5, 8, 9, and 10, while cover group 1 consists of cover codes 4, 7, 3/7, 4/7, 5/7 and 9/7.

Table 4
Distances (feet) Sampled for Juvenile Chinook Salmon HSC Data - Mesohabitat Types

Mesohabitat Type	Near-bank habitat distance sampled	Mid-channel habitat distance sampled
Bar Complex Glide	6385	5370
Bar Complex Pool	5756	5215
Bar Complex Riffle	8796	1230
Bar Complex Run	8770	2126
Flatwater Glide	10923	8391
Flatwater Pool	3534	1500
Flatwater Riffle	5712	1200
Flatwater Run	8286	11713
Off-Channel Area	900	0
Side-Channel Riffle	7995	270
Side-Channel Run	3700	0

Table 5
Distances (feet) Sampled for Juvenile Chinook Salmon HSC Data - Cover Types

Cover Type	Near-bank habitat distance sampled	Mid-channel habitat distance sampled
None	15100	13153
Cobble	20734	16127
Boulder	3473	2259
Fine Woody	8782	222
Branches	11541	841
Log	2126	365
Overhead	1476	0
Undercut	1766	0
Aquatic Vegetation	4852	1143
Rip Rap	908	6
Overhead + instream	15230	667

areas with depths up to four feet. The sampler consists of a steel-rod frame with fine-mesh seine material on the sides and brackets for a detachable net on the back. The net has a 3'x4' opening, a mesh size of 600 μm, and is mounted on a rectangular 3'x4' steel frame. The bottom of the sampler has a rubber foam lining to provide a tight seal with the substrate when the sampler is pressed down to the river bottom. The sampler requires three individuals - one to hold the sampler in place, and the other two individuals to clean off rocks within the 9-square-foot area, with the current carrying the macroinvertebrates into the net. Rocks are cleaned to a depth of four to six inches. Bedrock is cleaned with a 3"x6" scrub brush, while rocks are picked up and cleaned underwater by rubbing with neopreme gloves. Sites less than three feet deep are sampled by two individuals with snorkel gear, while sites over three feet are sampled by one individual with scuba gear. After sampling is completed, the net is detached from the sampler, the macroinvertebrates in the net are washed into the cod end of the net and then transferred to jars with 70% alcohol for transport back to the lab for analysis.

We are stratifying our sampling by season, habitat type, depth, velocity and substrate. Specifically, for each two-week sampling period, we are attempting to collect one sample in each combination of 1-foot increments of depth (up to 4 feet), 1-foot/sec increments of velocity (up to 4 feet/sec) and five ranges of substrate size, and to collect equal numbers of samples in riffle, run, glide and pool mesohabitat types. Sampling sites were selected based on the above stratification protocol with a tag placed at the sampling location. Before a sample is collected, the depth and mean column velocity at the sampling site are measured and the substrate size noted. To eliminate potential effects on the macroinvertebrate population due to changes in flow, we are requiring at least 30 days of stable discharge from Keswick Dam prior to sample collection. Our original sampling plan was to collect samples once every three months. However, frequent fluctuations of Keswick Dam releases during most of the year typically only leaves two periods which have relatively constant flows for 30 days: mid-summer, typically starting around early July; and mid-fall, typically starting around early October. Thus the only times suitable for sampling are in mid-August and mid-November.

We have now collected a total of 37 macroinvertebrate samples (nine in riffles, twelve in runs, five in pools and eight in glides). Ten samples were collected in FY99 (in July), while six samples were collect in November 1999[8] and twenty-one samples in August 2000. Keswick releases in the month prior to the November 1999 sampling averaged 6179 cfs ± 3%, while Keswick releases in the month prior to the August 2000 sampling averaged 14868 cfs ± 6%. The November 1999 sampling was halted after one week because Keswick releases started to ramp up, while the August 2000 sampling was halted one day into the second week because Keswick releases started to ramp down. Based on our experience to date, we can collect 20 samples per week. We plan to collect another 40 samples in November 2000, for a total of 77 samples. Given the stratification of the sampling by depth, velocity and substrate, this should provide enough samples to generate habitat suitability criteria.

[8] Only ten samples were collected in July 1999 and six samples in November 1999 due to equipment problems.

LOWER AMERICAN RIVER

As a result of the 115,000 cfs flood releases made into the lower American River in January of 1997, considerable morphological changes have occurred in many areas of the river including some of our previous study sites. As a result, CDFG inquired into the possibility that we collect additional hydraulic and structural data, and develop new spawning habitat models for fall-run chinook salmon on the lower American River.

We decided to run both PHABSIM and the 2-D habitat modeling program funded by the U.S.G.S. office in Fort Collins, Colorado to allow for additional comparisons of the 2-D model to PHABSIM. The 2-D model uses as inputs the bed topography and substrate of a site, and the water surface elevation at the bottom of the site, to predict the amount of habitat present in the site. The 2-D model will be run for each of the five study sites described in the FY98 annual report. The downstream-most PHABSIM transect will used as the bottom of the site, to provide water surface elevations as an input to the 2-D model. The upstream-most PHABSIM transect will be used as the top of the site, to calibrate the 2-D model - bed roughnesses are adjusted until the water surface elevation at the top of the site matches the water surface elevation predicted by PHABSIM.

Hydraulic Model Construction and Calibration

All of the data for the five American River spawning sites have been compiled and checked. PHABSIM data decks have been created and hydraulic calibration is almost complete for the American River spawning site transects. A final report on the PHABSIM portion of the American River study will be completed by the end of September 1999. Input files for the 2-D modeling program have been prepared and hydraulic calibration is in progress for all of the American River spawning sites. A final report on the 2-D modeling portion of the American River study will be completed by the end of December 1999.

BUTTE CREEK

Habitat Suitability Criteria (HSC) Development

Spawning

<u>Methods</u>

We began collecting habitat suitability criteria data for spring-run chinook salmon spawning in Butte Creek on September 27-30, 1999 and October 5, 1999. We sampled Butte Creek from Centerville Head Dam to Centerville Powerhouse, collecting habitat suitability data (depth, velocity and substrate) and counting the number of redds in each distinct spawning area. The upstream and downstream end of each spawning area was marked with a GPS unit. Flows in this portion of Butte Creek were stable at 40 cfs from the beginning of spring-run spawning (September 1) through the end of habitat suitability data collection. These steady flow conditions ensured that the measured depths and velocities were likely the same as those present at the time of redd construction. Flows below the Centerville Powerhouse dropped from around 170 cfs to around 120 cfs on September 21, 1999. As a result, we were unable to collect habitat suitability criteria from the Centerville Powerhouse to Parrot Phelan Dam in the fall of 1999, and just counted the number of redds in each distinct spawning area for this reach, during the first week of October 1999. As with the upper reach, the upstream and downstream end of each spawning area was marked with a GPS unit. We plan to collect habitat suitability criteria in the Centerville Powerhouse to Parrot Phelan Dam reach in the last week of September 2000.

For habitat suitability criteria data collection, all of the active redds (those not covered with periphyton growth) which could be distinguished were measured. Data were collected from an area adjacent to the redd which was judged to have a similar depth and velocity as was present at the redd location prior to redd construction. This location was generally about two to four feet upstream of the pit of the redd; however it was sometimes necessary to make measurements at a 45 degree angle upstream, to the side, or behind the pit. The data were almost always collected within six feet of the pit of the redd. Depth was recorded to the nearest 0.1 ft and average water column velocity was recorded to the nearest 0.01 ft/s. Substrate was visually assessed for the dominant particle size range (i.e., range of 1-2") at three locations: 1) in front of the pit; 2) on the sides of the pit; and 3) in the tailspill. Substrate embeddedness data were not collected because the substrate adjacent to all of the redds sampled was predominantly unembedded. The substrate coding system used is shown in Table 1.

Results

We collected habitat suitability criteria for 392 spring-run chinook salmon redds between Centerville Head Dam and Centerville Powerhouse. We counted in excess of 468 spring-run redds between Centerville Head Dam and Centerville Powerhouse and 459 spring-run redds between Centerville Powerhouse and Parrot Phelan Dam.

Field Reconnaissance and Study Site Selection

Field reconnaissance in FY2000 investigated potential study sites between Centerville Head Dam and Parrot Phelan Dam where two-dimensional (2-D) habitat modeling will be undertaken for spring-run chinook salmon spawning. Some of these sites may also be used for habitat modeling of spring-run chinook salmon rearing. The following section describes the methods employed and the results of FY2000 reconnaissance and study site selection efforts for this species.

Considering time and manpower constraints, seven study sites were selected for modeling spring-run chinook salmon habitat (Table 6). These seven sites are among those which received the heaviest use by spawning spring-run salmon in 1999. For the sites selected for modeling, the landowners along both riverbanks were identified and temporary entry permits were sent, accompanied by a cover letter, to acquire permission for entry onto their property during the course of the study.

Table 6
Sites Selected for Modeling Spring-run Chinook Salmon Spawning

Site Name	Reach	Number of Redds
Whiskey Flat	Centerville Head Dam - Centerville Powerhouse	13
Above Helltown 1	Centerville Head Dam - Centerville Powerhouse	30
Above Helltown 2	Centerville Head Dam - Centerville Powerhouse	> 80
Helltown Bridge	Centerville Head Dam - Centerville Powerhouse	39
Homestead	Centerville Powerhouse - Parrot Phelan Dam	18
Richbar	Centerville Powerhouse - Parrot Phelan Dam	58
Tailings	Centerville Powerhouse - Parrot Phelan Dam	28

Transect Placement (study site setup)

The modeling of spring-run chinook salmon spawning will be accomplished using two-dimensional modeling. The 2-D model uses as inputs the bed topography and cover of a site, and the water surface elevation at the bottom of the site, to predict the amount of habitat present in the site. The 2-D model avoids problems of transect placement, since the entire mesohabitat unit can be modeled. The 2-D model also has the potential to model depths and velocities over a range of flows more accurately than PHABSIM because it takes into account upstream and downstream bed topography and bed roughness, and explicitly uses mechanistic processes (conservation of mass and momentum), rather than Manning's n and a velocity adjustment factor. Other advantages of 2 -D modeling are that it can explicitly handle complex habitats, including transverse flows, across-channel variation in water surface elevations and flow contractions/expansions. The model scale is small enough to correspond to the scale of microhabitat use data with depths and velocities produced on a continuous basis, rather than in discrete cells. The 2-D model does a better job of representing patchy microhabitat features, such as gravel patches. The data can be collected with a stratified sampling scheme, with higher intensity sampling in areas with more complex or more quickly varying microhabitat features, and lower intensity sampling in areas with uniformly varying bed topography and uniform substrate and cover. Bed topography and substrate/cover mapping data can be collected at a very low flow, with the only data needed at high flow being water surface elevations at the top and bottom of the site and the flow and edge velocities for validation purposes. Only limited velocity data is required for validation purposes. In addition, alternative habitat suitability criteria, such as measures of habitat diversity, can be used.

Study sites were established in May and June 2000. The study site boundaries (top and bottom) were selected to coincide with the top and bottom of the boundaries of the heavy spawning use areas. The location of these boundaries was established during site setup by navigating to the points marked with the GPS unit during our redd counts in September and October 1999.

For each study site, a transect was placed at the top and bottom of the site. The bottom transect will be modeled with PHABSIM to provide water surface elevations as an input to the 2-D model. The upstream transect will be used in calibrating the 2-D model - bed roughnesses are adjusted until the water surface elevation at the top of the site matches the water surface elevation predicted by PHABSIM. Transect pins (headpins and tailpins) were marked on each river bank above the 500 cfs water surface level using rebar driven into the ground and/or lag bolts placed in tree trunks. Survey flagging was used to mark the locations of each pin.

Hydraulic and Structural Data Collection

Hydraulic and structural data collection began in May 2000. The data collected at the inflow and outflow transects include: 1) water surface elevations (WSELs), measured to the nearest .01 foot at a minimum of three significantly different stream discharges using standard surveying techniques (differential leveling); 2) wetted streambed elevations determined by subtracting the measured depth from the surveyed WSEL at a measured flow; 3) dry ground elevations to points above bankfull discharge surveyed to the nearest 0.1 foot; 4) mean water column velocities measured at a mid-to-high-range flow at the points where bed elevations were taken; and 5) substrate and cover classification at these same locations and also where dry ground elevations were surveyed. Data collected between the transects include: 1) bed elevation; 2) northing and easting (horizontal location); 3) cover; and 4) substrate. These parameters are collected at enough points to characterize the bed topography, substrate and cover of the site.

Water surface elevations have been measured at high (200-300 cfs), medium (100-150 cfs) and low (40 cfs) flows for the four sites between Centerville Head Dam and Centerville Powerhouse, and at high and medium flows for the three sites between Centerville Powerhouse and Parrot Phelan Dam. Water surface elevations will be collected at a low flow for these three sites in the fall of 2000. Velocity sets were collected for the transects at all sites at the high flow. Depth and velocity measurements were made by wading with a wading rod equipped with a Marsh-McBirney^{R} model 2000 or a Price AA velocity meter.

Substrate and cover along the transects was determined visually. Dry bed elevation, substrate and cover data along the transects has been collected for Whiskey Flat and Above Helltown 1 sites. Vertical benchmarks have been tied together for all sites except Richbar.

We have collected the data between the top and bottom transects by obtaining the bed elevation and horizontal location of individual points with a total station, while the cover and substrate are visually assessed at each point. To validate the velocities predicted by the 2-D model, depth, velocities, substrate and cover measurements were collected by wading with a wading rod equipped with a Marsh-McBirney[R] model 2000 or a Price AA velocity meter. The horizontal locations and bed elevations were determined by taking a total station shot on a prism held at each point where depth and velocity were measured. A minimum of 50 representative points were measured per site. To date, bed topography data has been collected for all sites except Helltown Bridge and Richbar, while validation velocities have been collected for all sites. We plan to complete all data collection for the seven sites during the fall of 2000.

REFERENCES

Gard, M. 1998. Technique for adjusting spawning depth habitat utilization curves for availability. Rivers: 6(2):94-102.

Rubin, S.P., T.C. Bjornn and B. Dennis. 1991. Habitat suitability curves for juvenile chinook salmon and steelhead development using a habitat-oriented sampling approach. Rivers 2(1):12-29.

APPENDIX A

SACRAMENTO RIVER JUVENILE CHINOOK SALMON STRANDING SITES

Stranding Site #	River Mile	River Bank	MHU #	Stranding Flow (cfs)[9]	Stranding Area (ft^2)
1	298.8	Left	139	21,250/5,000	19,579
2	300.5	Left	142		200
3A	300.6	Left	143	12,750/11,100	684
3B	300.6	Left	143	5,200/4,625	2,673
4	300.8	Left	143	7,400/6,580	4,838
5	301.4	Left	143	20,000/4,825	2,107
6	302	Right	143	8,128	1,200
7	300.2	Right	141	5,250/<3,250	2,850
8	299.9	Right	140	8,200/5,100	12,906
9	292.5	Left	100	6,409	1,319
10	294	Left	109	5,950	600
11	295.2	Left	113	<3,250	---
12	295.2	Left	113	<3,250	8,303
13	296.4	Left	129	4,500	1,056
14	296.5	Left	127	4,555	200,000
15	297	Left	127		5,373
16	297.4	Left	133	<3,250	75,024
17	296.9	Right	132	4,844	1,296
18	296.7	Right	130		
19	296.3	Right	123	5,950	3,164
20	295.5	N/A	114	9,337	13,640
21	295.3	N/A	114	6,050	47,611

[9] Sites 1 to 5, 7 and 8 are located above ACID and have a different stranding flow depending on whether the boards are in or out at ACID. The first flow is the stranding flow with boards out, while the second flow is the stranding flow with boards out.

Stranding Site #	River Mile	River Bank	MHU #	Stranding Flow (cfs)	Stranding Area (ft^2)
22	294.9	Right	111	<3,250	594
23	291.7	Right	96		4,497
24	291.8	Left	97	6,032	2,640
25	291.8	Right	97	4,248	5,612
26	289.5	Right	80		
27	293.7	N/A	107		106,000
28	293.7	Right	109		
29	293.7	Right	108	7,483	300
30	293.1	Right	104		26,978
31	292.8	Right	104		
32	292.8	Right	104	7,683	26,371
33	291.5	Right	91		21,500
34	290.3	Right	85		
35	289.3	Middle	75	7,898	4,397
36	289.3	Middle	75		36,320
37	288.5	Right	67		4,700
38	288.5	Right	67		
39A	291.7	Left	98		4,118
39B	291.7	Left	98		533
40	291.4	Left	91		
41	290.3	Left	85	7,330	5,921
41A	290.3	Left	85	4,640	3,233
42	290.3	Left	85		3,050
43	290.3	Left	85	4,440	9,020
44	290	Left	85		

Stranding Site #	River Mile	River Bank	MHU #	Stranding Flow (cfs)	Stranding Area (ft^2)
45A	290	N/A	84		
45B	290	N/A	84		
46	289.8	N/A	83		34,126
47	289.5	Left	81		
48	289.4	Left	75		
49	289.8	Left	83	4,640	5,066
50	289.6	N/A	82	4,440	40,594
51	289.5	N/A	78-80&82		345,115
52	289.4	N/A	76		3,827
53	289.4	N/A	76	4,666	17,375
54	289.4	N/A	76	4,766	4,261
55	289.8	Right	84		3,630
56	289.7	Right	84	4,440	2,088
57	285.2	Left	46		713
58	283.3	Left	45		
59	284.9	Left	46		
60	287.7	N/A	61		
60A	287.7	Right	61		1,330
60B	287.7	Right	61		
61	287.9	Left	63		
61A	287.9	Left	63		
62	287.8	N/A	61		
63	287.9	Right	64		480
64	287.6	Right	59		
65	287.5	Right	60		

Stranding Site #	River Mile	River Bank	MHU #	Stranding Flow (cfs)	Stranding Area (ft^2)
66	286.3	Right	53		
67	286.3	Right	53		
68	285.4	Right	48		
69	285.2	Right	47		
70	285.2	Right	47		
71	284.3	Right	45		
72	283.6	Right	45		
73	282.8	Right	43	5,750	
74	282.6	Right	42		
75	281.3	Right	36		
76	281.3	Right	36		5,918
77	281	Right	34		
78	280.6	Right	33		
79B	280.6	Right	33		120
79C	280.6	Right	33		
79A	280.4	Left	31		693
80	279.9	Right	28		459
81	279.1	Right	26		
82	273	Right	9		702
83	283.1	Left	44		
84	282.7	Left	43		
85	282.6	Left	41		
86	280.8	Right	34		
87	280.4	Right	30		
88	280.3	Right	30		

Stranding Site #	River Mile	River Bank	MHU #	Stranding Flow (cfs)	Stranding Area (ft^2)
88A	280.3	Right	30		
89	280.3	Right	30		
90	280.2	Left	30		
91	278.5	Left	20		3,683
92	276.9	Left	14		
93	275.6	Left	12		
94	275.6	Left	12		
95	271.7	Right	6		
96	287.6	Right	21		1,159
97	287.6	Right	21		

APPENDIX B

FINAL SACRAMENTO RIVER FALL-RUN CHINOOK SALMON SPAWNING HSI CRITERIA

Depth	HSI
0.00	0.00
0.40	0.00
0.50	0.22
0.62	0.30
0.78	0.41
0.93	0.54
1.08	0.67
1.24	0.79
1.39	0.89
1.54	0.96
1.70	1.00
1.85	1.00
48	0
100	0

Velocity	HSI
0.00	0.00
0.31	0.00
0.32	0.08
0.40	0.11
0.52	0.17
0.72	0.30
0.85	0.41
0.97	0.54
1.23	0.78
1.36	0.88
1.55	0.98
1.68	1.00
1.75	1.00
1.88	0.97
1.94	0.95
2.07	0.89
2.33	0.73
2.58	0.55
2.84	0.39
3.10	0.27
3.29	0.20
3.36	0.19
3.48	0.15
3.93	0.08
4.32	0.05
4.51	0.05
4.58	0.04
5.79	0.04
5.8	0
100	0

Sub Code	HSI
0.1	0
1	0
1.2	0.33
1.3	0.91
2.3	0.96
2.4	1.00
3.4	0.76
3.5	0.53
4.5	0.35
4.6	0.16
6.8	0.00
100	0.00